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Importance of Mathematics and Geometry in Architecture

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Abstract

Intentionally or unintentionally, from ages, architects, builders and construction experts have used mathematics as a very basic yet important tool for the soulful purpose of design, execution and finalization of building projects. In the history, architects were mathematicians and also some mathematicians were architect too. Vitruvius was a very well-known architect as well as famous mathematician. Mathematical readings of Pythagoras were later used in building proportions. Well known worker and user of golden ratio Leonardo Da Vinci along with many achievements was an architect too. The approach of this research paper is to come up with findings on importance of mathematics in architecture, as in geometry, from very important site analysis to final design of elevation or façade. Aim of the whole research is to come up with mathematical functions related to mensuration of building construction and Architectural Engineering. This paper is an initial part of the same research.

Keywords: *Geometry, form order and function, mensuration, golden section, pythagoras studies, patterns, history of architecture*

INTRODUCTION

The fundamental study of forms, shapes and spaces and their order along with their geometry contributes to the process of composition and designing of any element of architecture. Composition in architecture begins with space developing and their relations. Geometry and its study make an important input to this process by

dealing with studies of geometric figures, shapes and forms as elements and at the same place proportions, differences, angles positions and transformations as relations between them. The foundation of composition is built by structures. The word is derived from the Latin idea “structura” which means to associate together in order. Mathematics and

crucially geometry can be seen as a specific study of structures by considering collective sets of architectural elements and their relations as well as operations. This concept for an example was the background for an innovative approach to the composition of Mr. Richard Buckminster Fuller [1, 2].

Geometry can be stated as the science to describe structures and spaces. Max Bill in his artwork plays with geometric structures as method, for example in his variations of a single theme of project, the process of transformation from triangle to octagon was the final product and worked well [3, 4].

Max Bill was one of great artists who gave a thought on the relationship between art and structure. Through history of geometry and that of architecture there were developed some rules and standards based on geometry which formed the very basic concepts for architectural composition. In the following paper we will analyse the role of geometry in the sequential architectural design processes through several examples of contemporary architecture and along with them examples from history of architecture [5, 6].

HISTORY OF USE OF GEOMETRY IN ARCHITECTURE

Men in ancient time built to accommodate his spatial needs. Royal men used buildings as a royalty. Along with ornamental highlights their dwellings possessed a natural geometry-based in part on the structural characteristics of the materials that were available in appropriate diameter. As an example, we take the Sumer Reed house around 4000 B.C. The strong tall reeds of Euphrates delta were used as standard structural elements. These were bunched into bundles and bent to form either a circular or pointed arch. Reed matting was used as filler and the whole house was skinned with mud [7, 8]. House in its simplicity with geometric elements contains all the structural elements of the Romanesque or Gothic cathedral styles. The pyramids of Egypt are the best example of Egyptians' Understanding of Geometry. Pyramids reflect their attempt to model their human world on "cosmic order" to symbolize their stability. Geometry there was strongly related to religion and astronomy. The whole architecture of that time was based on "occult geometry system". This was a system of measurements, dimensions and proportion, which were considered as sacred and divine by religious leaders. In the Greek Period the tapering of

columns and manifestation of proportion and visual effects of building according to the dimension of columns of different order was the main concept of building design. The geometrical and technical achievements of Gothic Period were in brief, differentiating between bearing columns and non-bearing walls, utilizing the pointed arch, use of vault-supporting ribs, development of flying buttresses, large use of glass and tracery in various forms and shapes. The 13th century mason did not solve his structural problems with software and analysis as a modern engineer would, but by very skilful and insightful trial-and-error, aided by experience and geometric rules of design. The design depended more on getting the shape and then calculate the magnitude of forces acting on it. In the same way Renaissance Period also seen its own use of geometry in design of buildings. That was the period of start of architectural and engineering drawings. The development of projective geometry (orthographic and perspective) was an event that was of both architectural and geometrical importance. On the other hand the modern idea of building design focused on the functionality of building using materials like concrete, steel and glass and is reflected on building of period of modernism and even after, which makes

smart use of geometry and shape to get more and more from any piece of land without wasting any inch square.

CONCEPTS OF ARCHITECTURAL GEOMETRY

Golden Section

Such a fundamental principle of harmony derived from nature, applied in art, architecture and music can be seen in the golden section. The idea of the golden section shows the coherence of composition and geometry. This idea steps long time through history of architecture. Hippasos of Metapont (450 B.C.) found it in his research about the pentagon and the relation of its edge length and the diagonal. Euclid (325–270 B.C.) was the first who described the golden section precisely also as a continuous division. In the following time golden section was seen as the ideal proportion and the epitome of aesthetics and harmony. Especially in the renaissance, harmonic proportions were based on the geometric relations according the golden section in art, architecture as well as in music. Filippo Brunelleschi built Santa Maria del Fiore in Florence 1296 based on the golden section and the Fibonacci Numbers. Golden Rectangle, Golden Triangle, Golden Spiral, Penrose Tiling, Pentagon and Pentagram are some

kind of Golden geometry based on golden ratio [9, 10].

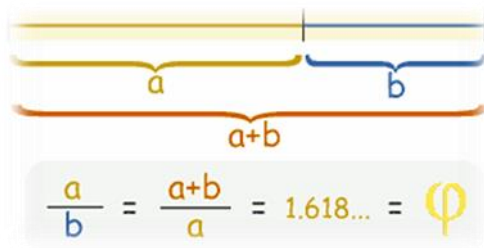


Fig. 1: Golden Ratio or Golden Section Ratio.

Fractal Geometry

The mathematical history of fractals began with mathematician Karl Weierstrass in 1872 who introduced a Weierstrass function which is continuous everywhere but differentiable nowhere. In 1904 Helge von Koch refined the definition of the Weierstrass function and gave a more geometric definition of a similar function, which is now called the Koch snowflake. In 1915, Waclaw Sielpinski constructed self-similar patterns and the functions that generate them. Georg Cantor also gave an example of a self-similar fractal. In the late 19th and early 20th, fractals were put further by Henri Poincare, Felix Klein, Pierre Fatou and Gaston Julia. In 1975, Mandelbrot brought these work together and named it 'fractal'. Fractals can be constructed through limits of iterative schemes involving generators of iterative functions on metric spaces Iterated

Function System (IFS) is the most common, general and powerful mathematical tool that can be used to generate fractals. The iteration procedure must converge to get the fractal set [11, 12]. Therefore, the iterated functions are limited to strict contractions with the Banach fixed-point property. Cantor set, Sierpinski Triangle, Menger sponge, Dragon curve, Space filling curve, Mandelbrot set are some of best examples of fractal geometry.

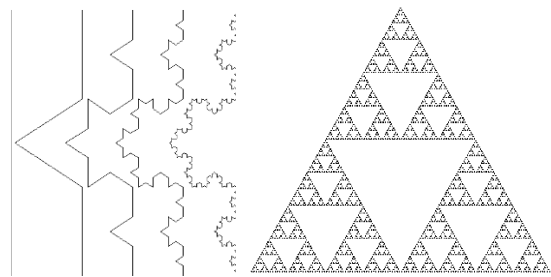


Fig. 2: Examples of Fractal Progression.

Moreover, IFS provides a connection between fractals and natural images. It is also an important tool for investigating fractal sets. In the following, an introduction to some basic geometry of fractal sets will be approached from an IFS perspective. In a simple case, IFS acts on a segment to generate contracted copies of the segment which can be arranged in a plane based on certain rules [13, 14].

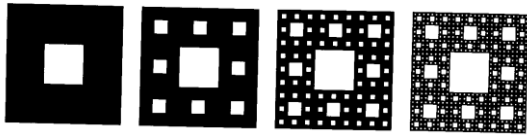


Fig. 3: An Example of Cantor's Set.

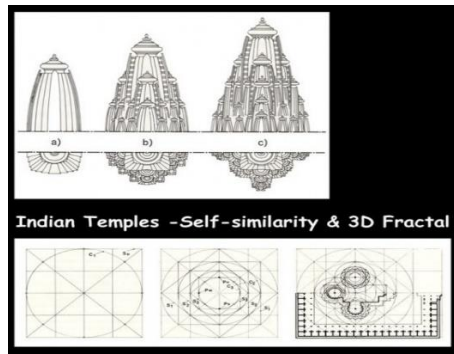


Fig. 4: Fractal Application in Temple Design.

IMPORTANCE OF GEOMETRY IN ARCHITECTURE

Geometric and Architectural Space Concepts

The architectural space is based on a geometric space concept. Especially, in the creation process architecture is thought in relation to a geometric space. Robin Evans analyses the relationship between geometry and architecture: "The first place anyone looks to find the geometry in architecture is in the shape of buildings, then perhaps the shape of the drawings of the buildings. These are the locations where geometry has been, on the whole, stolid and dormant. But geometry has been active in the space between and the space at either end." According Evans, in history

of architecture you find this misunderstanding of the role of geometry. In his historical study he refers to the relations between Gaspard Monge's Descriptive Geometry and Jean-Nicolas Louis Durand's theory of architecture. Durand taught architecture at l'École Polytechnique in Paris at the same time as Monge around 1800. Durand developed a universal planning grid for architecture. Evans describes that Durand's grid architecture is based on the misunderstanding of the spatial coordinate system. Instead of understanding the coordinate system in an abstract way, he transformed the coordinate planes directly in architecture as floor and walls [15, 16].

Geometry for Strength

Foundations being most important part of building for strength are constructed simple rectangle based cubes as they are easy to construct and give maximum efficiency and are good with the form working. On the other hand pile foundations are constructed cylindrical as they are drilled in earth minimum friction is required and at the same volume and lesser surface area cylinder is best. Triangle on the other hand is said to be the most stable shape. And for the same reason is used as most reliable members of building when it comes to load bearing and

stable structures may it be geodesic domes or big trusses.

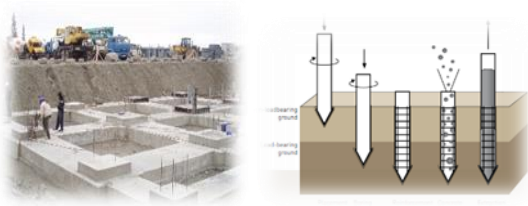


Fig. 5: Rectangular and Pile Foundation.

Geometry for Performance

Geometric application for performance in architecture can be simply understood as shape selection for maximum output. Like dome, or hemispherical roof have numbers of advantages over flat roof as it gives column less space as the load of roof is directly transferred to the rim of hemisphere and also the hemispheric space being useless can hold the hot air with stack effect and can gradually can be disposed from the roof. And on other side conical roof are generally used to cover tower like structures and pitched of triangular prism like roof is used when run off of water and snow is main concern.



Fig. 6: Pitched Roof and Domed Roof Coverings.

Geometry for Aesthetics and Ambience

The market success of industrial products strongly depends on their aesthetic character, i.e., the emotional reaction that the product is able to evoke. To achieve their aim designers have to act on specific shape properties, but at present they are not directly supported in this by existing digital tools for model definition and manipulation, mainly because of the still missing mathematical formalisation of the properties themselves. The European project FIORES-II (GRD1-1999-10785-Character Preservation and Modelling in Aesthetic and Engineering Design), started in April 2000, aims at investigating and identifying the links between emotional shape perception and geometry and to create, through their mathematical formalization, more user friendly tools for aesthetic design

Relationships between a Physical Form and its Emotional Message

In order to develop modelling tools to allow designers to quickly attain the desired emotional message, it is necessary to understand the procedures they follow to achieve their objectives. Within the FIORES-II project, design activities in different industrial fields have been analysed in depth and the language used in different phases of the design cycle has

been studied. It emerged that the terms strictly related to emotional values (e.g, dynamic, aggressive, etc.) that express the objectives to be achieved by the end product are mainly used when designers talk with marketing people. On the other hand, during the creation and modification of the digital model, designers communicate their aesthetic intent using a more detailed and restricted set of terms corresponding to shape properties. In this phase they provide instructions on which elements and properties have to be changed to realise their objective (e.g, making a curve a bit more accelerated, or decreasing the tension of its curvature) and to fulfil marketing directives. This second set of terms represents the first link between low-level geometric properties and the high-level features of a product. Therefore, in order to identify links between message and geometric shape, we envisage a two-level mapping: the first level links geometric properties to design terms; the second links these latter to the emotional message.

Geometry and Religion

Sacred geometry is used as a religious, philosophical, and spiritual term to explain the fundamental laws of the universe covering Pythagorean geometry and the perceived relationships between

geometrical laws and quantum mechanical laws of the universe that create the geometrical patterns in nature. Many Gothic cathedrals were built using proportions derived from the geometry inherent in the cube and double-cube; this tradition continues in modern Christian churches to the present time. Churches, temples, mosques, religious monuments, altars, tabernacles; as well as for sacred spaces such as temenoi, sacred groves, village greens and holy wells, and the creation of religious art. In sacred geometry, symbolic and sacred meanings are ascribed to certain geometric shapes and certain geometric proportions, according to Paul Calter and others.

Hinduism

The Agamas are a collection of Sanskrit, Tamil and Grantha, scriptures chiefly constituting the methods of temple construction and creation of idols, worship means of deities, philosophical doctrines, meditative practices, attainment of six fold desires and four kinds of yoga. Elaborate rules are laid out in the Agamas for Silpa (the art of sculpture) describing the quality requirements of the places where temples are to be built, the kind of images to be installed, the materials from which they are to be made, their dimensions,

proportions, air circulation, lighting in the temple complex etc. The Manasara and Silpasara are some of the works dealing with these rules. The rituals followed in worship services each day at the temple also follow rules laid out in the Agamas.

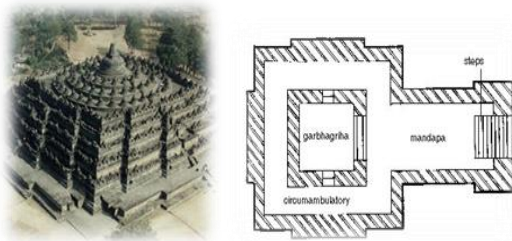


Fig. 7: *Application of Agamas in Temple Planning.*

Islam

Islamic decoration makes great use of geometric patterns which have developed over the centuries. Many of these derived from various earlier cultures: Greek, Roman, Byzantine, Central Asian, and Persian. They are usually distinguished from the arabesque, the term for decoration in Islamic art based on curving and branching vegetal forms. But sometimes foliage and linear geometric patterns are combined in a single design, and some purely abstract linear patterns adopt designs that seem clearly derived from vegetal arabesque ones. The geometric designs have evolved into beautiful and highly complex patterns, still used in many modern day settings.

The square and rectangle play a significant role in Islamic architecture. Some of the reason for this is façades built from rectangular bricks. This ornamental brickwork casts shadows in the strong desert sunlight and creates a three-dimensional effect. A recurring motif is a small central square turned 45 degrees within a larger square. Another source for the square motif is woven baskets.

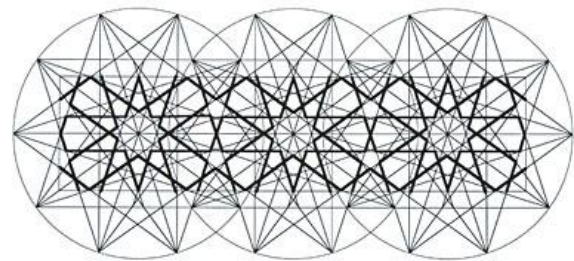


Fig. 8: *Cosmic Geometric Patterns in Islam.*

The Persianate world is the main area with buildings with decorative brickwork, especially during the Seljuk period; the Great Mosque of Cordoba is another example further west. The eight-pointed star is another common motif in Islamic architecture, often found in tile-work and other media. Star patterns are extremely complex when the outer points are joined together and other intersections connect in a systematic way. The Alhambra palace in Granada, Spain is a famous example of repeating motifs which occur in the tile and stucco decoration. Octagons appear in

Islamic architecture in various shapes. They frequently occur in marble floors. The Citadel of Aleppo in Syria contains marble opus sectile floors, which utilize the square and the eight-pointed star. Pierced screens (jali in India) are another common location for geometric decoration.



Fig. 9: Geometry in Jali Designs.

Going Beyond Geometry

Parametric design is a process based on algorithmic thinking that enables the expression of parameters and rules that, together, define, encode and clarify the relationship between design intent and design response. Parametric design is a paradigm in design where the relationship between elements is used to manipulate and inform the design of complex geometries and structures. The term 'Parametric' originates from mathematics (Parametric equation) and refers to the use of certain parameters or variables that can be edited to manipulate or alter the end result of an equation or system. Parametric

design is not a new concept and has always formed a part of architecture and design. The consideration of changing forces such as climate, setting, culture, and use has always formed part of the design process.

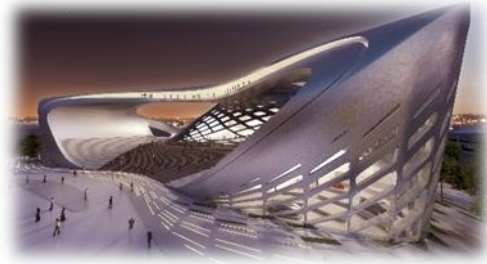


Fig. 10: Example of Parametric Design.

Parametric modelling systems can be divided into two types of systems:

- Propagation based systems where you compute from known to unknowns with a dataflow model.
- Constraint systems which solve sets of continuous and discrete constraints.

CONCLUSION

The relationship between architectural design and geometry starts with the notion of harmony as the principle for all sciences and creations. The analysis of the antique comprehension of harmony shows the geometrical root and the superior idea of this concept for all sciences and designing disciplines. Today, the various sciences and arts are in most cases strongly separated. Therefore, there is the risk that

the powerful relationship between geometry and architecture gets lost. Steven Holl, who refers in his architectural work to geometry and other sciences, noticed: “For example Johannes Kepler’s Mysterious Cosmo-graphical united art, science, and cosmology.

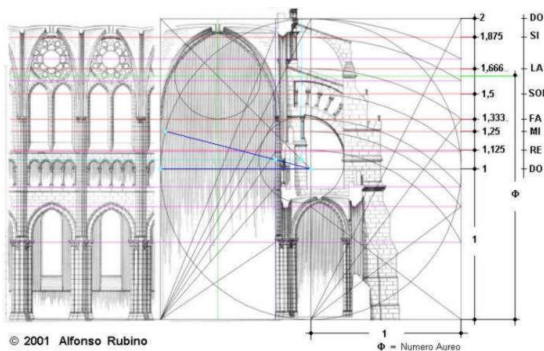


Fig. 11: Application of Golden Rati in Roman Temple Design.

Today, specialization segregates the fields; yawning gaps prohibit potential cross-fertilization.” By remembering the historical relations between geometry and architectural design we help to keep the background of our culture but also to understand the fruitful combination between geometrical thinking and architectural designing. By integrating experiments on using geometric structures for designing in the architecture curriculum we should reflect this relationship and try to develop new impulses for geometrical based designing in architecture. Only few examples were shown here in an overview. There are

more efforts necessary in the future to work out this relationship in detail, historical and theoretical, from an architectural and a geometrical point of view as well as to experience and apply it in the practice of architectural design.



Fig. 12: Identifying Geometrical Characteristics in a Building.

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